**DepartmentofElectricalandElectronicsEngineering**

**Electrical Measurements and Sensors (25EE305)**

# UNIT – II

## POTENTIOMETERS & INSTRUMENT TRANSFORMER

## Working Principle of Potentiometer

This is a very basic instrument used for comparing emf two cells and for calibrating ammeter, voltmeter and watt-meter. The basic **working principle of potentiometer** is very very simple. Suppose we have connected two battery in head to head and tale to tale through a galvanometer. That means the positive terminals of both battery are connected together and negative terminals are also connected together through a galvanometer as shown in the figure below

.

it is clear that if the voltage of both battery cells is exactly equal, there will be no circulating current in the circuit and hence the galvanometer shows null deflection. The **working principleof potentiometer** depends upon this phenomenon.

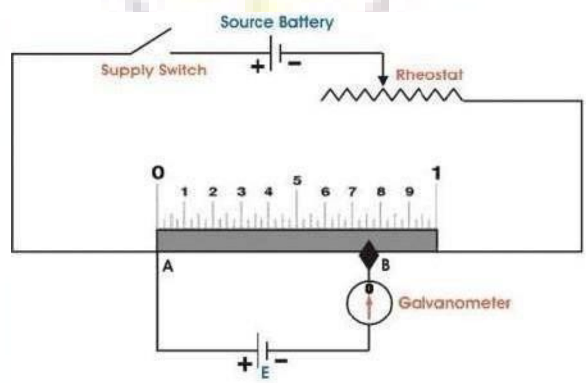
Now let's think about another circuit, where a battery is connected across a resistor via a switch and a rheostat as shown in the figure below voltage-drop-calculation/ across the resistor. As there is a voltage drop across the resistor, this portion of the circuit can be considered as a voltage source for other external circuits. That means anything connected across the resistor will get voltage. If the resistor has uniform cross section throughout its length, the electrical resistance per unit length of the resistor is also uniform throughout its length.

voltage drop per unit length of the resistor is also uniform. Suppose the current through the resistor is i A and resistance per unit length of the resistor is r Ω. Then the voltage appears perunit length across the resistor would be 'ir' ans say it is v volt.

positive terminal of a standard cell is connected to point A on the sliding resistor and negative terminal of the same is connected with a galvanometer. Other end of the galvanometer is in contact with the resistor via a sliding contact as shown in the figure above. By adjusting this

sliding end, a point like B is found where, there is no current through the galvanometer, hence no deflection of galvanometer.

That means emf of the standard cell is just balanced by the voltage-drop-calculation/ appears across AB. Now if the distance between point A and B is L, then it can be written emf of standard cell E = Lv volt. As v (voltage drop per unit length of the sliding resistor) is known andL is measured from the scale attached to the resistor, the value of E i.e. emf of standard cell can also be calculated from the above simple equation very easily.




## DC Crompton's Potentiometer :

DC Crompton's potentiometer is the laboratory-type potentiometer that is used to measure unknown emf effectively with a great degree of precision.

DC Crompton's potentiometer works on the principle of a slide wire potentiometer. In other words, the DC Crompton potentiometer is a modified version of a slide-wire potentiometer. It basically consists of a small slide wire which is circular in shape and a dial switch with calibrated resistors, as shown in the figure below.

In the figure shown,

- B = Battery
- Rh = Rheostat
- G = Galvanometer
- R = Protective resistance which is of order of 10 KΩ
- S = Double throw switch
- C = Standard cell

In DC Crompton's potentiometer, the dial switch is divided into fifteen steps with each step having a resistance of 10Ω. Hence, the total resistance of dial switch is equal to 150Ω (15 X 10 = 150). The slide wire is in the form of a circular wire and has a resistance of 10Ω, with a single turn. A double-throw switch is provided for standardization and for measuring the unknown emf, one after the other.

A protective resistance is connected in series with the galvanometer in order to protect the galvanometer and is shorted when the galvanometer reaches the balanced condition. As the working current provided by the battery is 10 mA, the voltage drop across each step is 0.1 V and hence it has a total range of 1.5 V (1.5 x 10 = 15 V).

If circular slide wire has 200 divisions, then each division in slide wire has a resolution of 0.0005 V (0.1/200 = 0.0005). Hence, it is possible to measure the readings up to 0.0001 V with great precision and accuracy by taking readings up to 1/5th division in the scale.

First, the potentiometer is to be standardized to the standard cell voltage (1.0186 V) by keeping the dial switch at 1.0 V and slide wire at 0.0186. After making these adjustments, switch S is operated in calibrate mode and key k is closed and the rheostat is adjusted in such a way that, the galvanometer shows null deflection. With this, the potentiometer is standardized to the voltage of standard cell which is connected between the terminals 1 and 1'.

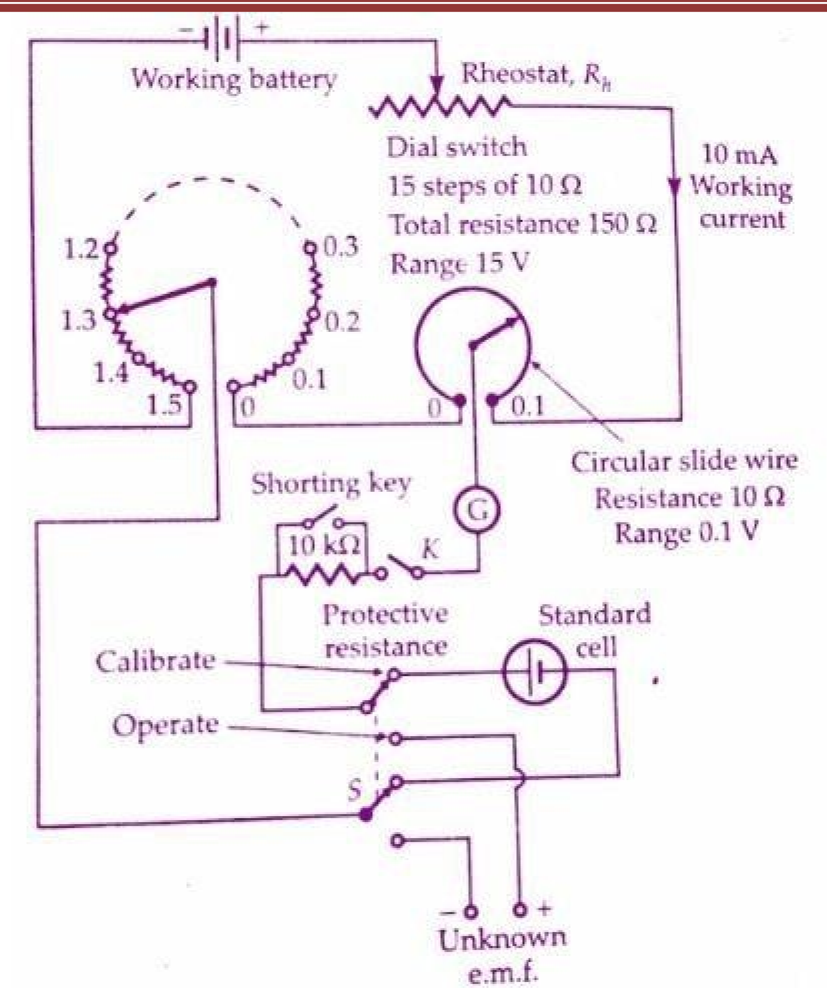
Now, the switch is thrown into the operating mode for measuring the unknown emf connected between terminals 2 and 2'. The value of unknown emf can be measured directly from the dial switch and circular slide wire, after balancing the galvanometer to show null deflection. In this way, an unknown emf can be measured with great precision using DC Crompton's potentiometer.

Standardization of DC Crompton's Potentiometer :

DC Crompton potentiometer is a laboratory-type potentiometer, with high precision. Here, the long slide wire is replaced with extension coils having the resistance same as that of the slide wire.

Standardization is defined as the process of adjusting the working current of the potentiometer such that the voltage drop across the section of slide wire is equal to the standard reference voltage. The following are the steps involved in the standardization of DC Crompton's potentiometer.

- Settings are made such that, the sum of the voltage across the dial resistors and the slide wire is equal to the standard cell voltage.
- The switch is closed to calibrate the positions and the rheostat is set for null deflection. The galvanometer key is tapped and the resistance is kept in the circuit to protect the galvanometer.
- As soon as zero deflection is obtained, the protective resistance is replaced by a short-circuit, and then final settings are done for null deflection using a rheostat.

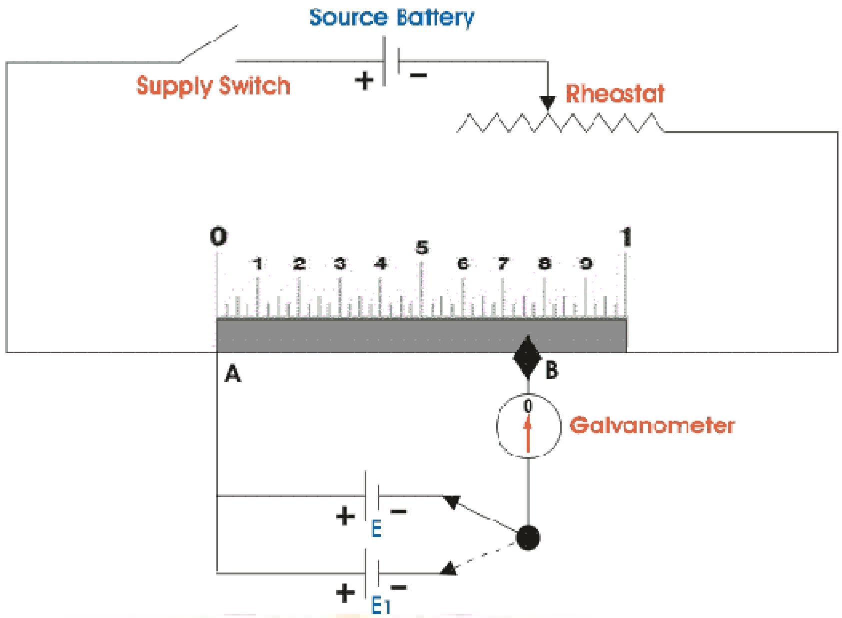



## DC POTENTIOMETER CAN COMPARE EMFS OF TWO DIFFERENT CELLS

Two cells whose emf's are to be compared are joined as shown in the figure below. The positive terminals of the cells and source battery are joined together. The negative terminals of the cells are joined with the galvanometer in turn through a two way switch. The other end of the galvanometer is connected to a sliding contact on the resistor. Now by adjusting sliding contact on the resistor, it is found that the null deflection of galvanometer comes for first cell at a lengthof L on the scale and after positioning to way switch to second cell and then by adjusting the sliding contact, it is found that the null deflection of galvanometer comes for that cell at a lengthof $L_1$ on the scale.Let's think of the first cell as standard cell and it's emf is E and second cell is unknown cell whose emf is $E_1$. Now as per above explanation, E = Lv volt and
$L_1 = L_1v$ volt Dividing one equation by other, we get

$$\frac{E_1}{E} = \frac{L_1}{L}$$

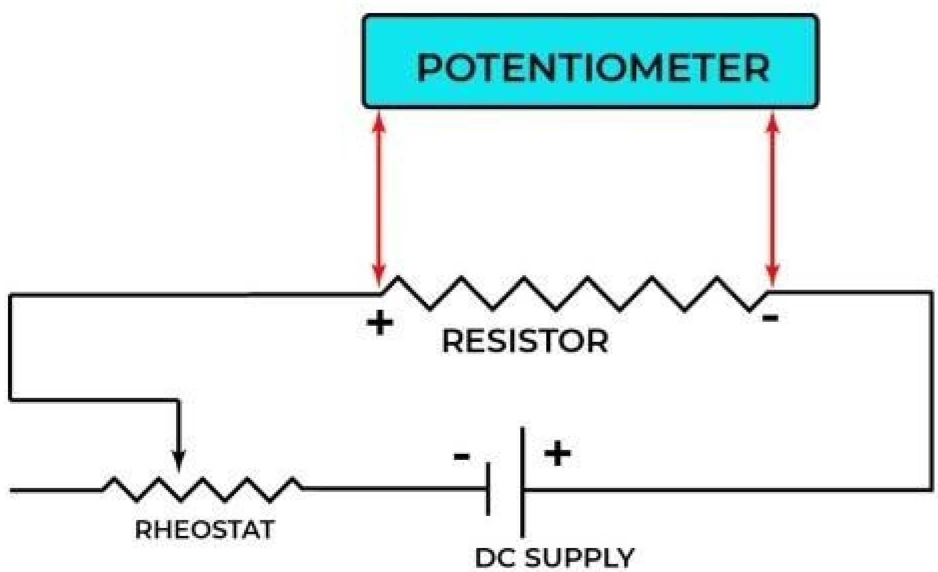
As the emf of the standard cell is known, hence emf of the unknown cell can easily be determined.




## Measurement of current

The unknown current I, whose value is to be measured is passed through a resistor R. The value of the resistor is such that voltage drop across it may not exceed the range of the potentiometer.

The circuit diagram of current measurement by potentiometer is shown below:

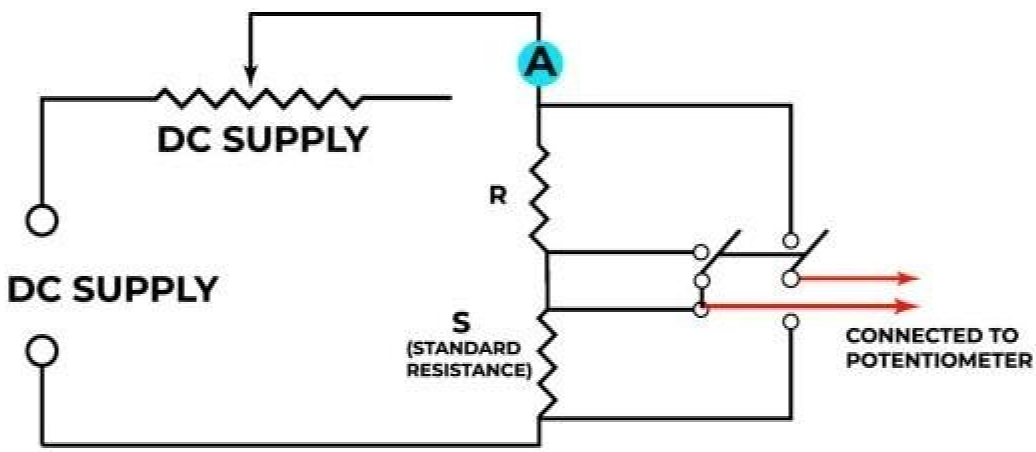



So, the value of the unknown current is the voltage drop across the resistor divided by the value of the resistor.

I = V/R

## Measurement of resistance

An unknown resistance is connected in series with a standard resistance S. A rheostat controls the current in the circuit. A two-pole double throw switch is also used in the circuit. The circuit is shown below:




When the two poles double throw switch is put in position 1, the unknown resistance is connected to the potentiometer.
Let the reading of the potentiometer be $V_R$

$$V_R = IR \qquad \text{(i)}$$

Now the switch is put in position 2, this connects the standard resistor S to the potentiometer. Let the reading of potentiometer be Vs

$$Vs = IS \qquad \text{(ii)}$$

From i and ii

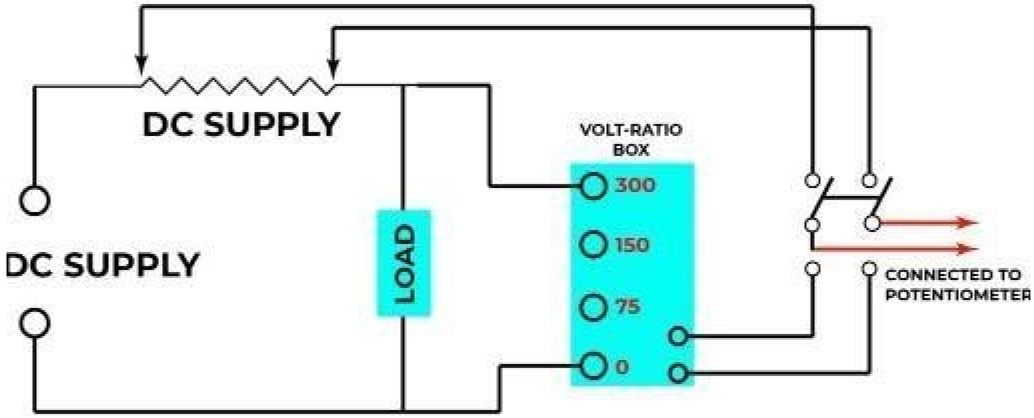
$$V_R/Vs = IR/IS$$

$$R = (V_R/Vs)*S$$

The value of R is calculated accurately.

## Measurement of power

In the measurement of power, 2 measurements are made. One is across the resistor S connected in series with the load and the other is across the output terminals of voltage—ratio box.
The load current is calculated from the voltage drop across the standard resistor




Power measurement by potentiometer

The voltage drop across the load is calculated by the potentiometer reading across the output terminal of the voltage-ratio box

Load current $I = V_S/S$

Where VS is the voltage drop across the standard resistor The voltage drop across the load $Vl = kV_R$

Where, k = multiplying factor of the voltage-ratio box.

So, the power consumed, $P = V_L I$

$P = K*V_R*(V_S/S)$

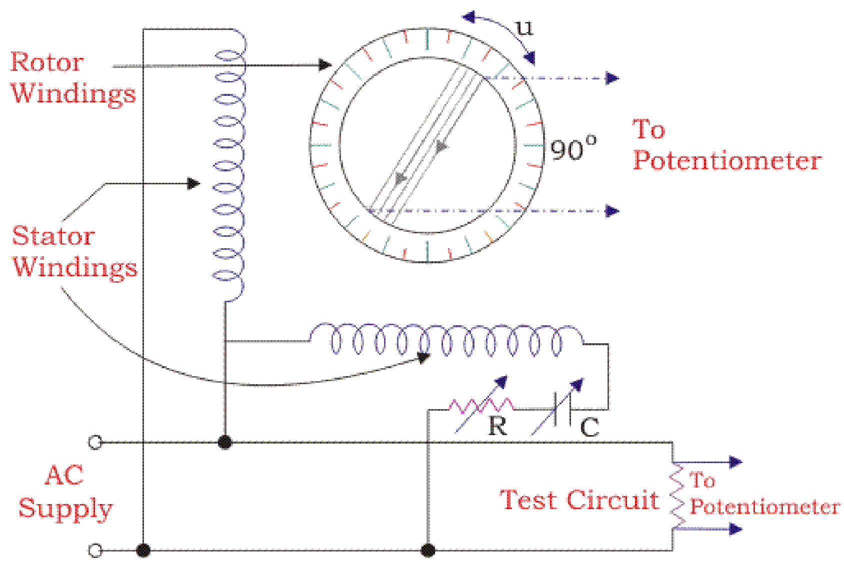
## AC Potentiometer

The Potentiometer is an instrument which measures unknown voltage by balancing it with a known voltage. The known source may be DC or AC. The working phenomenon of DC potentiometer and **AC potentiometer** is same. But there is one major difference between their measurements, DC potentiometer only measures the magnitude of the unknown voltage. Where as, AC potentiometer measures both the magnitude and phase of unknown voltage by comparing it with known reference. There are two types of AC potentiometers:

1. Polar type potentiometer.
2. Coordinate type potentiometer.

## Polar type Potentiometer

In such type of instruments, two separate scales are used to measure magnitude and phase angle on some reference of the unknown e.m.f. There is a provision on the scale that it could read phase angle up to 3600. It has electrodynamometer type ammeter along with DC potentiometer and phase-shifting transformer which is operated by single phase supply. In phase-shifting transformer, there is a combination of two ring-shaped laminated steel stators connected perpendicularly to each other as shown in the figure. One is directly connected to power supply and the other one is connected in series with variable resistance and capacitor. The function of the series components is to maintain constant AC supply in the potentiometer by doing small adjustments in it. Between the stators, there is laminated rotor having slots and winding which supplies voltage to the slide-wire circuit of the Potentiometer. When current start flowing from stators, the rotating field is developed around the rotor and due to it e.m.f. is induced in the rotor winding. The phase displacement of the rotor emf is equal to rotor movement angle from its original position and it is related to stator supply voltage. The whole arrangement of winding are done in such a way that the magnitude of the induced emf in the rotor may change but it does not affect the phase angle and it can be read on the scale fixed on the top of the instrument.




Polar Type Potentiometer

The induced emf in rotor winding by stator winding 1 can be expressed as

$$E_1 = K\ I\ sin\omega t\ cos\ \varnothing \ldots\ldots\ldots\ldots (1)$$

The induced emf in the rotor winding by the stator winding 2,

$$E_2 = K\ I\ sin(\omega t + 90^o)\ cos(\varnothing + 90^o)$$
$$= -K\ I\ cos\omega t\ sin\varnothing \ldots\ldots\ldots\ldots (2)$$

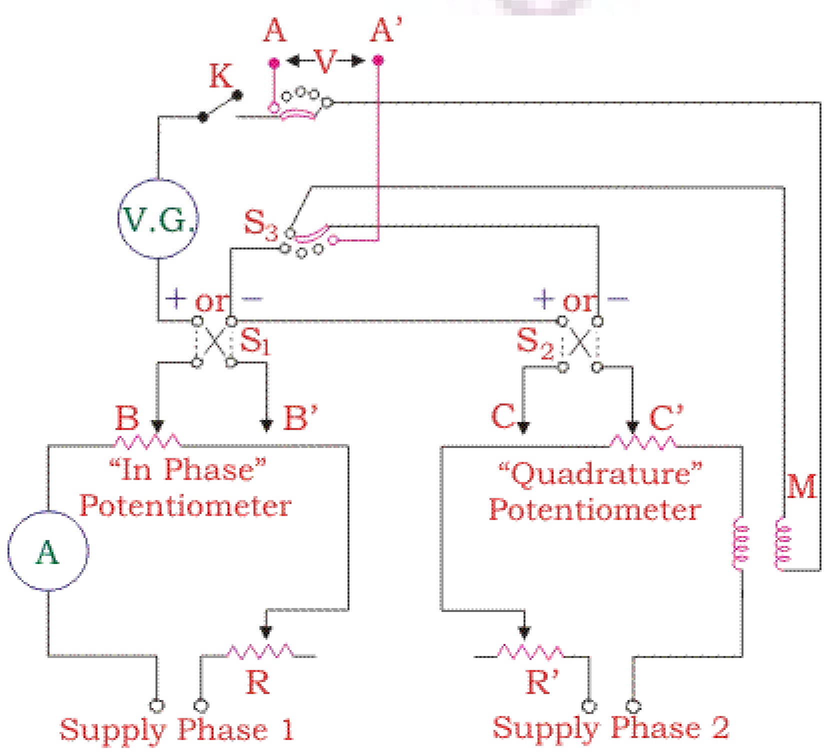
From equation (1) and (2), we get

$$E = K\ I\ (sin\omega t\ cos\varnothing - cos\omega t\ sin\varnothing)$$

Therefore, resultant induced emf in the rotor winding due to two stator winding $E = K\ I sin\ (\omega t - \varnothing)$ Where, Ø gives the phase angle.

## COORDINATE TYPE POTENTIOMETER

In **coordinate AC potentiometer**, two separate potentiometers are caged in one circuit as shown in the figure. The first one is named as the in-phase potentiometer which is used to measure the in-phase factor of an unknown e.m.f. and the other one is named as quadrature potentiometer which measures quadrature part of the unknown e.m.f. the sliding contact AA' in the in-phase potentiometer and BB' in quadrature potentiometer are used for obtaining the desired current in the circuit. By adjusting rheostat R and R' and sliding contacts, the current in the quadrature potentiometer becomes equal to the current in the in- phase potentiometer and a variable galvanometer shows the null value. $S_1$ and $S_2$ are signs changing switches which are used to change the polarity of the test voltage if it is required for balancing the Potentiometer. There are two step-down transformers $T_1$ and $T_2$ which isolate potentiometer from the line and give an earthed screens protection between the winding. It also supplies 6 volts to potentiometers. Now to measure unknown e.m.f. its terminals are connected across sliding contacts AA' using selector switch $S_3$. By doing some adjustments in sliding contacts and rheostat, the whole circuit gets balanced and galvanometer reads zero at the balanced condition. Now the in-phase component $V_A$ of the unknown e.m.f.is obtained from the in-phase potentiometer and quadrature component $V_B$ is obtained from quadrature potentiometer.




Coordinate AC potentiometer

$$V = (V_A^2 + V_B^2)^{1/2}$$

Thus, the resultant voltage of the coordinate

**AC potentiometer** is

And the phase angle is given by $\varnothing = tan^{-1}(V_B/V_A)$

## Applications of AC Potentiometer

1. Measurement of self-inductance.
2. Calibration of voltmeter.
3. Calibration of Ammeter.
4. Calibration of wattmeter.

# INSTRUMENT TRANSFORMERS

**Introduction of Instrument Transformers**

Instrument Transformers are used in AC system for measurement of electrical quantities i.e. voltage, current, power, energy, power factor, frequency. Instrument transformers are also used with protective relays for protection of power system. Basic function of Instrument transformers is to step down the AC System voltage and current. The voltage and current level ofpower system is very high. It is very difficult and costly to design the measuring instruments for measurement of such high level voltage and current. Generally measuring instruments are designed for 5 A and 110 V.

The measurement of such very large electrical quantities, can be made possible by usingthe Instrument transformers

## Advantages of Instrument Transformers

1. The large voltage and current of AC Power system can be measured by using small rating measuring instrument i.e. 5 A, 110 – 120V.
2. By using the instrument transformers, measuring instruments can be standardized. Which results in reduction of cost of measuring instruments. More ever the damaged measuring instruments can be replaced easy with healthy standardized measuring instruments.
3. Instrument transformers provide electrical isolation between high voltage power circuit and measuring instruments. Which reduces the electrical insulation requirement for measuring instruments and protective circuits and also assures the safety of operators.
4. Several measuring instruments can be connected through a single transformer to power system.
5. Due to low voltage and current level in measuring and protective circuit, there is low power consumption in measuring and protective circuits.

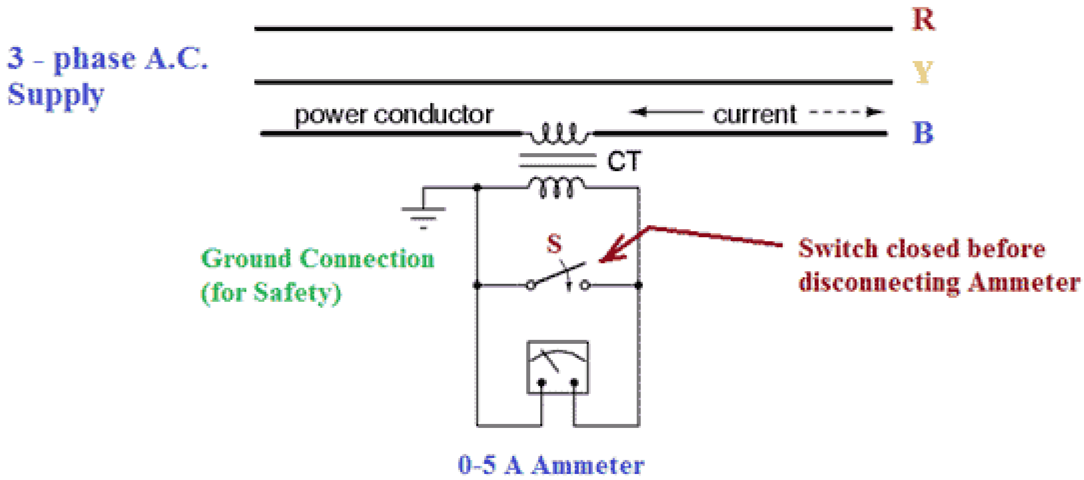
## Types of Instrument Transformers

Instrument transformers are of two types –

1. Current Transformer(C.T.)
2. Potential Transformer(P.T.)

## Current Transformer (C.T.)

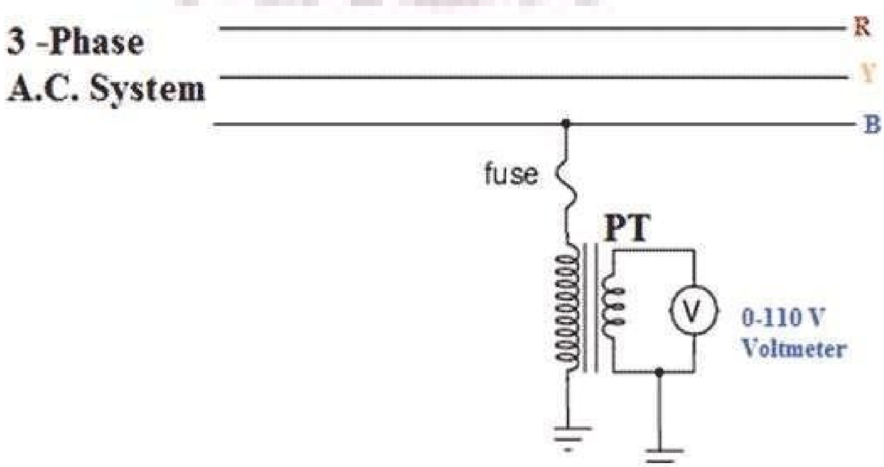
Current transformer is used to step down the current of power system to a lower level to make it feasible to be measured by small rating Ammeter (i.e. 5A ammeter). A typical connection diagram of a current transformer is shown in figure below.




**Current Transformer (C.T.)**

Primary of C.T. is having very few turns. Sometimes bar primary is also used. Primary is connected in series with the power circuit. Therefore, sometimes it also called series transformer**.**

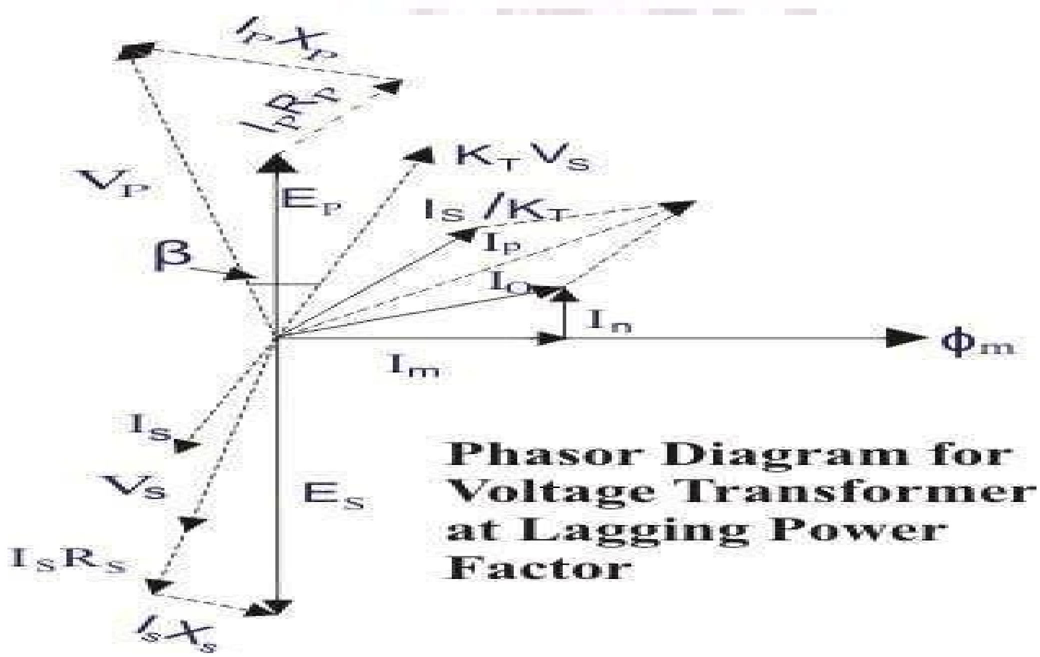
The secondary is having large no. of turns. Secondary is connected directly to an ammeter. As the ammeter is having very small resistance. Hence, the secondary of current transformer operates almost in short circuited condition. One terminal of secondary is earthed to avoid the large voltage on secondary with respect to earth. Which in turns reduce the chances of insulation breakdown and also protect the operator against high voltage. More ever before disconnecting the ammeter, secondary is short circuited through a switch 'S' as shown in figure above to avoid the high voltage build up across the secondary.




**Potential Transformer (P.T.)**

| Sl. No. | Current Transformer (C.T.) | Potential Transformer (P.T.) |
|---|---|---|
| 1 | Connected in series with power circuit. | Connected in Parallel with Power circuit. |
| 2 | Secondary is connected to Ammeter. | Secondary is connected to Voltmeter. |
| 3 | Secondary works almost in short circuited condition. | Secondary works almost in open circuited condition. |
| 4 | Primary current depends on power circuit current. | Primary current depends on secondary burden. |
| 5 | Primary current and excitation vary over wide range with change of power circuit current | Primary current and excitation variation are restricted to a small range. |
| 6 | One terminal of secondary is earthed to avoid the insulation break down. | One terminal of secondary can be earthed for Safety. |
| 7 | Secondary is never be open circuited. | Secondary can be used in open circuit condition. |

## Error in PT or Potential Transformer or VT or Voltage Transformer




$I_s$ - Secondary current.

Es - Secondary induced emf.

Vs - Secondary terminal voltage

Rs - Secondary winding resistance.

Xs - Secondary winding reactance.

Ip - Primary current.Ep - Primary induced emf.

Vp - Primary terminal voltage. Rp - Primary winding resistance.Xp - Primary winding reactance.

$K_T$ - Turns ratio = Numbers of primary turns/number of secondary turns.$I_0$ - Excitation current.

Im - Magnetizing component of I0.Iw - Core loss component of I0.

Φm - Main flux.

β - Phase angle error.

As in the case of current transformer and other purpose electrical power transformer, total primary current $I_p$ is the vector sum of excitation current and the current equal to reversal of secondary current multiplied by the ratio $1/K_T$.

$$Hence,\ I_p = \frac{I_0 + I_s}{K_T}$$

If $V_p$ is the system voltage applied to the primary of the PT, then voltage drops due to resistance and reactance of primary winding due to primary current $I_p$ will come into picture. After subtracting this voltage drop from $V_p$, $E_p$ will appear across the primary terminals. This $E_p$ is equal to primary induced emf. This primary emf will transform to the secondary winding by mutual induction and transformed emf is $E_s$.Again this $E_s$ will be dropped by secondary winding resistance and reactance, and resultant will actually appear across the burden terminals and it is denoted as $V_s$. So, if system voltage is $V_p$, ideally $V_p/K_T$ should be the secondary voltage of PT, but in reality; actual secondary voltage of PT is $V_s$.

**Voltage Error or Ratio Error in Potential Transformer (PT) or Voltage Transformer (VT)**

The difference between the ideal value $V_p/K_T$ and actual value $V_s$ is the voltageerror or ratio error in a potential transformer, it can be expressed as,

$$\% \text{ voltage error} = \frac{V_p - K_T.V_s}{V_p} \times 100\ \%$$

## Phase Error or Phase Angle Error in Potential or Voltage Transformer

The angle ′β′ between the primary system voltage $V_p$ and the reversed secondaryvoltage vectors $K_T.V_s$ is the phase error.

## Cause of Error in Potential Transformer

The voltage applied to the primary of the potential transformer first drops due to the internal impedance of the primary. Then it appears across the primary windingand then transformed proportionally to its turns ratio, to the secondary winding.

This transformed voltage across the secondary winding will again drop due to theinternal impedance of the secondary, before appearing across burden terminals.

This is the reason of errors in **potential transformer**.

**Ratio Error Phase Angle Error in Current TransformerDefinition of Instrument Transformer**

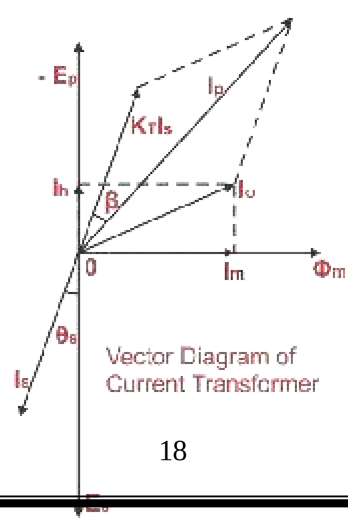
Instrument transformers means **current transformer** and voltage transformer are used in electrical power system for stepping down currents and voltages of thesystem for metering and protection purpose.

## Current Transformer(CT)

A CT is an instrument transformer in which the secondary current is substantially proportional to primary current and differs in phase from it by ideally zero degree.

## Error in Current Transformer or CT

But in an actual CT, errors with which we are connected can best be considered through a study



Vector Diagram of Current Transformer

of phasor diagram for a CT
, Is - Secondary
current Es - Secondary
induced emf.Ip -
Primary current.
Ep - Primary induced emf.
KT - Turns ratio = Numbers of secondary turns/number of primary
turns.I0 - Excitation current.
Im - Magnetizing component
of I0.Iw - Core loss
component of I0.
Φm - Main flux. Let us take flux as reference.

EMF $E_s$ and $E_p$ lags behind the flux by 90°. The magnitude of the passers $E_s$ and $E_p$ are proportional to secondary and primary turns. The excitation current $I_o$ which is made up of two components $I_m$ and $I_w$. The secondary current $I_0$ lags behind the secondary induced emf $E_s$ by an angle $\Phi_s$. The secondary current is now transferred to the primary side by reversing $I_s$ and multiplied by the turns ratio $K_T$. The total current flows through the primary $I_p$ is then vector sum of $K_T$ $I_s$ and $I_0$.

**The Current Error or Ratio Error in Current Transformer or CT** From above passer diagram it is clear that primary current $I_p$ is not exactly equal to the secondary current multiplied by turns ratio, i.e. $K_T I_s$. This difference is due to
the primary current is contributed by the core excitation current. The error in current transformer introduced due to this difference is called current error of CTor some times ratio error in current transformer.

$$\text{Hence, the percentage current error} = \frac{|I_p| - |K_T . I_s|}{I_p} \times 100\ \%$$

## Phase Error or Phase Angle Error in Current Transformer

For a ideal CT the angle between the primary and reversed secondary current vector is zero. But for an actual CT there is always a difference in phase between two due to the fact that primary current has to supply the component of the exiting current.The angle between the above two phases in termed as phase angle error in current transformer or CT. Here in the pharos diagram it is β the phase angle error is usually expressed in minutes.

## Cause of Error in Current Transformer

The total primary current is not actually transformed in CT. One part of the primary current is consumed for core excitation and remaining is actually transformers with turns ratio of CT so there is **error in current transformer** means there are both **ratio error in current transformer** as well as a **phase angle errorin current transformer**.

## How to Reduce Error in Current Transformer

It is desirable to reduce these errors, for better performance. For achieving minimum error in current transformer, one can follow the following,

1. Using a core of high permeability and low hysteresis loss magnetic materials.
2. Keeping the rated burden to the nearer value of the actual burden.
3. Ensuring minimum length of flux path and increasing cross-sectional area ofthe core, minimizing joint of the core.
4. Lowering the secondary internal impedance.